Crash Injury Severity of Older Drivers in Iowa

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According to the US National Highway Traffic Safety Administration, 175,000 older individuals were injured in traffic crashes in 1997, representing 14 percent of all traffic fatalities and 13 percent of all vehicle occupant fatalities in that year. Compared with the fatality rate for drivers aged 25ñ69 years, the rate for drivers 70 years or older is nine times higher. With the aging of the United Statesí population, the safety of older drivers is becoming more crucial every day. Using 1990 through 1997 reported crash data from the State of Iowa, the authors investigated causal factors that may contribute to the severity of injuries inflicted on older drivers (age ≥ 65 years) involved in single vehicle crashes. The authors used the ordered probit modeling technique and investigated factors from vehicle, roadway, and driver characteristics that can potentially contribute to injury severity. Some environmental, temporal, and policy factors were also investigated. The objective was to isolate factors leading to more severe injuries among older drives so that transportation agencies may focus on those to improve safety for older drivers in particular. Analysis results indicate that advancing driver age and lack of occupant protection inside the vehicle significantly contributed to the severity of older driversí injuries. Crashes that involved an overturned vehicle or a vehicle striking a fixed object were more injurious to older drivers. Older driver injuries were more severe in farm vehicles as compared to injuries in other types of vehicles. Additionally, injuries to older drivers were more severe when crashes occurred on curves and in rural areas. The authors discuss some of the improvements that may be of interest to transportation agencies desiring to improve the safety of older drivers. Key words: injury severity, traffic safety, older drivers, ordered probit.

INTRODUCTION

According to the National Highway Traffic Safety Administration (NHTSA) of the United States Department of Transportation, 175,000 individuals 70 years of age or older were injured in traffic crashes in 1997. This represents 14 percent of all traffic fatalities, and 13 percent of all vehicle occupant fatalities in 1997 (*1*). Calculated on the basis of estimated annual travel, the fatality rate of older drivers is the highest among different age-based driver groups and is nine times as high as that of drivers between the ages of 25 and 69 years. Furthermore, according to the Federal Highway Administration (FHWA), the number of older persons who are licensed to drive continues to increase (*2*). The United Statesí population is undergoing a major demographic transformation that is resulting in a larger proportion of older individuals in the population (*3, 4, 5*). With the aging population and increase in older licensed driver numbers, the safety of older drivers is becoming more crucial every day.

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This paper focuses on factors that contribute to the severity of older driver injuries in single vehicle crashes reported in the State of Iowa. The paper provides a review of literature on crashes that involve older persons and crash injury severity, describes the data analyzed in this study, presents the data analysis, and concludes with a discussion on the findings.

LITERA TURE REVIEW

The literature reviewed in this study indicates the vulnerability of older drivers involved in traffic crashes. Previous research utilizing Iowa crash data indicates that both age and gender are good predictors of injury severity in multiple-vehicle broadside and angle collisions (*6*) and head-on collisions (*7*). Additionally, older drivers experience a higher frequency of crashes per unit distance traveled. The two studies indicate that older drivers are more likely to suffer severe or fatal injuries in a crash, and that changes in driving ability due to reductions in visual capacity, peripheral vision, and cognitive process (e.g., attention and reaction time) are important factors in increased crash involvement. Physiological changes such as bone density loss, age-related diseases, and reduction in resiliency to injury are identified as contributory factors to injury severity of older drivers.

A report by the Iowa Department of Transportationís Safety Management System Task Force on Speed Limits indicates that deterioration of driving skills with advancing age of drivers is an important attribute, and speed differential is a problem for older drivers (*5*). A Nebraska study that examined issues related to safety of older drivers (*8*) indicates deficiencies in driving knowledge and deficits in physical, perceptual, and cognitive abilities as issues related to the safety of older drivers. Researchers using data from Hawaii determined that very young and very old drivers are most likely to be at fault in crashes (*9*). Richardson et al. (*10*) report that older drivers have higher incidences of involvement in rear-end, sideswipe, and broadside crashes. A study by Kim et al. (*11*) mentions the possibility that ìresilience after injuryî or ìother factors affecting injuryî might affect the odds of older drivers being injured in a crash. Another study examining run-off-road crashes reports that age is not a significant factor in such crashes (*12*).

DATA COMPILA TION

A number of factors can potentially affect injury severity in a single vehicle crash. The authors conceptualized those factors under several major categories: policy actions, roadway characteristics, driver attributes, vehicle characteristics, crash characteristics, and environ-

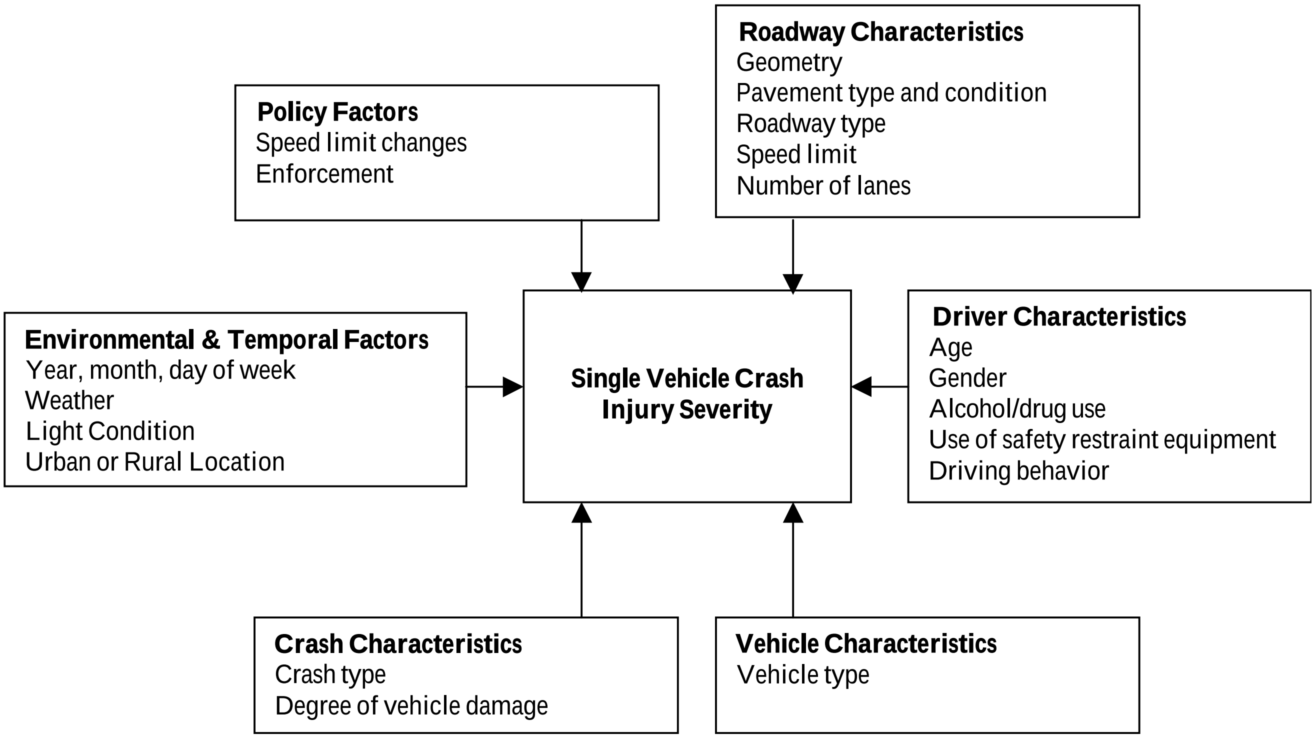

FIGURE 1 Conceptualization of injury severity

mental and temporal characteristics (see Figure 1). The presence of so many factors under these categories complicates the relationships between these factors and injury severity. To discern meaningful relationships among older driver injury severity and the influencing factors, the authors restricted the available data (1990 through 1997) in several ways. First, the reported crash data were limited to single vehicle crashes involving older drivers (age ≥ 65 years) in which an injury was reported. Injuries on crash record forms in Iowa are rated on the KABCO scale of severity: Killed (fatality), Class A (incapacitating), Class B (evident), Class C (possible), and PDO (property damage only/other). The authors limited the crash data to the categories represented by KABC, i.e., the property damage crashes were taken out. Second, single vehicle crashes involving pedestrians were removed from the data due to the involvement of multiple persons (driver and pedestrian) in the crash and the possibility that the reported injuries may be those of the pedestrian and not of the driver. The resulting file contained 1,984 observations representing single vehicle crashes in Iowa involving injury to older drivers.

The maximum speed limit on some rural expressways in Iowa was raised from 88 km per hour (55 mph) to 105 km per hour (65 mph) in 1996 after the US Congress repealed the National Maximum Speed Limits in November 1995. Single vehicle crashes involving older drivers that occurred before and after 1996 on those particular routes were identified to study the impact of increased speed limit on injury severity of older drivers.

Figure 2 presents older driver gender and age distributions across the four levels of injury severity under investigation. Overall, 590 C-type, 948 B-type, 361 A-type, and 85 K-type, single vehicle crashes involving older drivers were reported during the study period. Except in the C-type category, male drivers were over-involved in all injury severity levels. The numbers of male and female drivers reporting C-type injuries were equal in the data file. Many more male and female drivers in the 65 to 75 years of age category reported injuries (of all levels of severity) when compared to drivers in the 76 to 85 years category. Similarly, many more male and female drivers in the 76 to 85 years category reported injuries (of all levels of severity) when compared to drivers in the 85+ years category.

Figure 3 presents the distribution of different types of vehicles and the damage sustained by the vehicle during the reported crash.

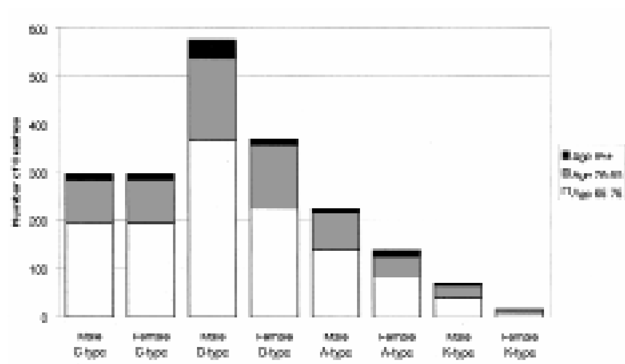

FIGURE 2 Gender and age distribution across different injury severity levels

Passenger cars were involved in most of the crashes followed by pickup trucks. These two vehicle categories reported the heaviest damage to vehicles as well.

Figure 4 presents the distribution of crashes across type of roadway and as a function of type of environment (rural and urban). Most

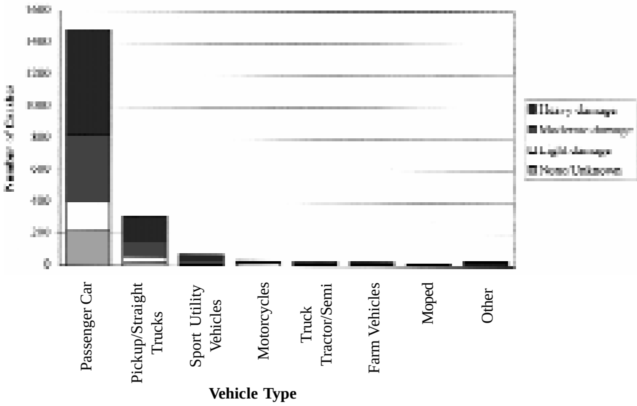

FIGURE 3 Vehicle type and vehicle damage severity

crashes involving older drivers occurred on county roads and state/US routes. Most crashes occurred in the rural environment, which is not surprising given the rural setting of Iowa.

MODELING INJURY SEVERITY

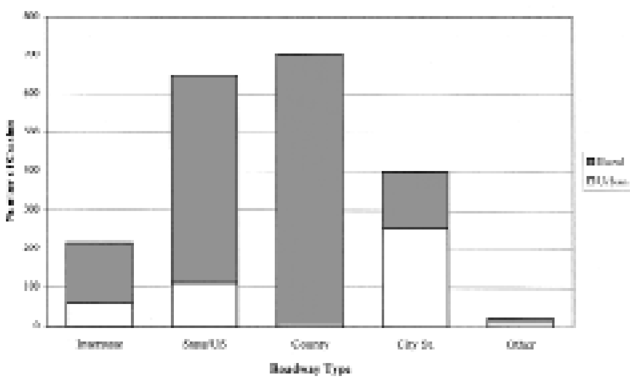

FIGURE 4 Type of roadway and environment

The dependent variable in this study is the severity of injury sustained by older drivers involved in single vehicle crashes. The crash severity scale is ordinal (K-type representing most severe and C-type representing least severe injuries). The appropriate models to use for ordinal data are ordered probit and ordered logit models. Several researchers have used the ordered probit model in safety-related studies (*13, 14, 15*). The ordered probit model provides accurate estimation of the impact of various explanatory variables on the probability of crash severity. A discussion on the form of the ordered probit model follows.

According to Greene (*16*), the ordered probit model has the following form:

$$y^* = \beta'\mathbf{x} + \varepsilon \tag{1}$$

where:

y^* is the dependent variable (injury severity in this case),

β' is the vector of estimated parameters,

$\mathbf{x}$ are the explanatory variables, and

ε is the normally distributed error term.

The parameter estimates (β') represent the effect of explanatory variables on the underlying injury scale. Based upon this specification, the probability of the dependent variable falling in any ordered category is:

$$\text{Prob}(y=n) = \Phi(\mu_n - \beta'\mathbf{x}) - \Phi(\mu_{n-1} - \beta'\mathbf{x}) \tag{2}$$

ε has a cumulative distribution denoted by $\Phi(\cdot)$ and a density function denoted by $\phi(\cdot)$. An individual falls in category n if $\mu_{n-1} < y^* < \mu_n$; the injury data , y, are related to the underlying latent variable, y*, through thresholds μ_n, where n=1, 2, 3, 4. We have the following probabilities.

$$\text{Prob}(y=n) = \Phi(\mu_n - \beta'\mathbf{x}) - \Phi(\mu_{n-1} - \beta'\mathbf{x}),\quad n=1, 2, 3, 4. \tag{3}$$

Where $\mu_0 = 0$ and $\mu_3 = +$, and where $\mu_1 < \mu_2$ are defined as two thresholds between which categorical response are estimated. Ordered probit estimation will give the threshold values of μ_2 and μ_3 and parameters β'. The thresholds, μ_2 and μ_3, show the range of the normal distribution associated with the specific values of the response variable. The remaining parameters, β', represent the effect of changes in explanatory variables on the underlying scale. The marginal impacts of factors **x** on the underlying injury propensity can be evaluated as:

$$\text{Prob}(y=n)/..x = -[\phi(\mu_n - \beta'\mathbf{x}) - \phi(\mu_{n-1} - \beta'\mathbf{x})]\beta,\quad n=1, 2, 3, 4. \tag{5}$$

Computation of marginal effects is meaningful for the ordered probit model because the estimated parameter coefficients do not represent the magnitudes of variables **x** on the intermediate categories of the dependent variable. A measure of the model goodness of fit (ρ^2) can be calculated as:

$$\rho^2 = 1 - [\ln L_b / \ln L_0] \tag{6}$$

Where $\ln L_b$ is the log likelihood at convergence and L_0 is the restricted log likelihood. The ρ^2 measure is bound by zero and one. Values of ρ^2 closer to one indicate better fit of the model.

MODELING RESULTS

The authors estimated an ordered probit model with injury severity of older drivers as the dependent variable. Independent variables from all the categories of factors that may affect injury severity were tried in the model (see Figure 1). Table 1 presents the modeling results. The rho-squared (ρ^2) term for the ordered probit model, a goodness-of-fit measure, indicates a reasonable fit between the model and the data. A positive estimated coefficient in the model implies increased severity with increase in the value of the explanatory variable. Independent variables from each category that were tried in the model specification as well as the ones that the model indicated as significantly contributing to injury severity are discussed below. The marginal values provide the impacts that a unit change in the individual independent variables have on different levels of injury severity when all other variables are held at their means.

The model indicates a positive estimated coefficient for driver age, which is statistically significant at the 95 percent confidence level (a z-statistic of 1.96 or higher indicates significance at the 95 percent confidence level). This indicates that advancing age increases the propensity of more severe injury, as expected by the authors. The positive sign of the estimated coefficient for gender (coded as male = 1, female = 0) in the model indicates that male older drivers experience more severe injuries. The absence of occupant restraint systems inside was investigated by including an indicator variable in the model specification. As expected, the model indicated strong statistical evidence that older drivers in vehicles without any restraint systems incurred more severe injuries. Although not statistically significant, further probing indicated that older drivers under the influence

TABLE 1 Ordered Probit Model Results
(dependent variable: Injury severity of older driver in single vehicle crash; coding: C-type injury = 0, B-type injury = 1, A-type injury = 2, and K-type injury = 3)

Category	Independent Variable	Estimated Coefficient	z-statistic	Marginal Effects			
				C-type	B-type	A-type	K-type
Driver characteristics	Age (in years)	0.011	2.763	-0.0038	0.0005	0.0024	0.0008
	Gender (male = 1, female = 0)	0.220	4.240	-0.0748	0.0106	0.0480	0.0162
	Non-use of seat belt (not used = 1, used = 0)	0.497	8.062	-0.1691	0.024	0.1084	0.0367
	Drunk (under influence =1, otherwise = 0)	0.133	1.034	-0.0451	0.0064	0.0289	0.0098
Roadway characteristics	Speed limit (in km per hour)	0.002	1.450	-0.0007	0.0001	0.0004	0.0001
	Curves in level terrain (curve in level terrain =1, otherwise = 0)	0.218	2.531	-0.0741	0.0105	0.0475	0.0161
Vehicle characteristics	Farm vehicle (farm vehicle = 1, otherwise = 0)	0.989	4.389	-0.3361	0.0477	0.2155	0.0729
Crash Characteristics	Vehicle overturned (overturned = 1, otherwise = 0)	0.186	1.915	-0.0634	0.009	0.0406	0.0137
	Fixed object struck (hit fixed object = 1, otherwise = 0)	0.158	2.141	-0.0537	0.0076	0.0344	0.0116
	Animal related crash (animal involved = 1, otherwise = 0)	-0.246	-1.827	0.0837	0.0119	-0.0537	-0.0181
Environment	Clear weather (clear weather = 1, otherwise = 0)	0.105	2.116	-0.0359	0.0051	0.023	0.0078
	Rural environment (rural = 1, urban = 0)	0.161	2.469	-0.0547	0.0078	0.0351	0.0119
Model-specific attributes	Constant	-0.899	-2.843	0.3058	0.0434	-0.1961	-0.0663
	μ_2	1.356	36.778	-	-	-	-
	μ_3	2.403	38.423	-	-	-	-

Model Summary Statistics
No. of observations: 1984 Degrees of freedom: 12 Log likelihood: -2002.326 Restricted log likelihood: -2297.544
Rho-squared (ρ^2): 0.128

of alcohol tend to experience more severe injuries as compared to older drivers not under the influence.

Several variables from the roadway category that may contribute to the severity of injuries to older drivers in single vehicle crashes were examined. The model indicated that crashes occurring at curves in level terrain were more injurious compared to crashes occurring at other locations. The roadway network in Iowa consists mostly of straight highway sections. It is possible that older drivers may not fully compensate in terms of vehicle speed for curves on the highways resulting in more severe injuries at curves on level terrain when compared to other locations. Speed limit was included in the model specification to evaluate its effect on the injury severity of older drivers. As expected, the estimated coefficient for speed limit is positive. However, the variable is not statistically significant. Differences in severity of injury across highway sections and intersections were explored (by using an indicator variable), but the model did not indicate the presence of any statistical evidence. The indicator variable was then excluded from the model specification to improve model fit.

The type of vehicle may also considerably influence severity of driver injury. Several types of vehicles (passenger car, pickup truck, etc.) were tried in the model specification. Interestingly, farm vehicle crashes resulted in significantly higher injuries compared to other types of vehicles. This finding is important because only 17 percent of farm vehicles in the data set had incurred heavy damage, yet the injuries sustained in farm vehicles were more severe. Farm vehicle traffic in Iowa significantly increases during the spring and fall, and although usually slow moving, they are unique and significantly different in design than regular vehicular traffic on roadways. Several types of crashes were explored to study their effects on severity of injuries to older drivers. As expected, the model indicated that overturned vehicles resulted in more severe injuries to older drivers compared to other types of crashes. Also, crashes in which vehicles struck a fixed object resulted in more severe injuries. However, crashes involving animals were not as injurious as other types of crashes, also as expected by the authors.

The authors investigated environmental factors such as weather conditions at the time of crash. The model indicated that injuries to older drivers tended to be more severe if the weather was clear. This may be so because older drivers tend to adjust their driving behavior, e.g., slow down, during adverse weather conditions. The effects of rural and urban environment were investigated by using an indicator variable for rural locations. The model indicated the presence of statistical evidence that rural crashes tend to be more severe compared to urban crashes. Other variables such as different light conditions and crash year (1990–1997) were investigated but not found to be statistically significant and hence not included in the model specification.

Finally, the authors tried to evaluate the effects of speed limit changes on some Iowa divided multilane highways during 1996 on the injury severity of older drivers. Indicator variables were created for crashes that occurred before and after 1996 on those specific highways where speed limits were changed. The model did not indicate statistically significant differences in the injury severity of older drivers before and after the increase in speed limit. The two indicator variables were excluded from the model specification to reduce the "noise" in the model. Although, there is evidence in the literature that increased speed limits result in more injurious crashes, it appears that the increase in speed limits on selected highways in Iowa did not increase injury severity of older drivers. It is clear, however, that injury severity of drivers in other age groups and/or multiple vehicle crashes were affected by the increased speed limits, as the Iowa Department of Transportation has documented an overall increase in fatalities, injuries, and total crashes following the speed limit change (*17*). This issue requires more in-depth research and collection of additional crash data after 1996 to verify a statistically significant trend.

SUMMARY AND DISCUSSION

The model indicated that several explanatory variables from various categories were important in predicting injury severity of older drivers involved in single-vehicle crashes. Advanced driver age, gender (male), absence of occupant restraint systems in vehicles, and use of alcohol contributed to severity of injuries. Among roadway characteristics, crashes occurring on curves in level terrain were more injurious. Injuries in farm vehicles were more severe compared to injuries in other vehicles. Crashes that resulted in overturned vehicles or crashes in which vehicles struck fixed objects were more injurious to older drivers. Animal-related crashes were less injurious than other types of crashes. Crashes occurring in a rural environment and crashes occurring under clear weather were also more injurious to older drivers. The modeling effort did not indicate evidence that older driver injury severity in single-vehicle crashes increased on selected Iowa highways due to an increase in speed limit.

The findings have several important implications for the safety of older drivers. Advancing age increases the propensity of more severe injury, and older drivers need to be aware of this when they are considering a reduction in driving. Transportation agencies may consider installing curve warning signs or using rumble strips on long sections of highways that are followed by curves to alert older drivers to oncoming curves in the road geometry. Older driver injuries in crashes involving farm vehicles need further investigation to assess causal factors behind the high level of injury severity. Transportation agencies may focus their attention on reducing crashes that involve overturned vehicles and crashes that involve vehicles hitting fixed objects. The effects of policy actions, such as an increase in speed limits, need further investigation.

This study did not explore variations in injury severity within subgroups of older drivers. Further, it did not compare crash injury severity of older drivers to that of younger drivers. Future studies may focus on investigation of subgroups of older drivers and comparison to injuries sustained by younger drivers.

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